Materials Science & Engineering A 701 (2017) 7–15

Contents lists available at ScienceDirect

Materials Science & Engineering A

journal homepage: www.elsevier.com/locate/msea

Microstructure and mechanical anisotropy of the hot rolled Mg-8.1Al-0.7Zn-0.15Ag alloy

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ARTICLE INFO

Keywords:
Magnesium alloy
Hot rolling
Dynamic precipitation
Dynamic recrystallization
Twinning
Anisotropy

ABSTRACT

The microstructure and mechanical anisotropy of the hot rolled Mg-8.1Al-0.7Zn-0.15Ag (wt%) sheets were investigated. Dynamic precipitation and dynamic recrystallization (DRX) are the main features of the microstructures. Compared with the sheet rolled at 673 K, the sheet rolled at 633 K exhibits higher level of dynamic precipitates, finer grain size, more uniform microstructure and better strength. TEM observations reveal that the spherical $Mg_{17}Al_{12}$ phases which precipitate dynamically do not possess specific orientation with the matrix. Meanwhile, the migration of dynamic recrystallized (DRXed) grain boundaries is retarded by the pinning of fine particles, thereby leading to a remarkable grain refinement. DRX within the compression twins only appear in the alloy sheet rolled at 673 K and give rise to a weakened basal texture. The study on mechanical anisotropy behavior suggests that the reduced anisotropy of the sheet rolled at 633 K may ascribe to the activation of prismatic $< a >$ slip due to the presence of $Mg_{17}Al_{12}$ phases.

1. Introduction

Magnesium and its alloys are of current interest in the automotive and aerospace industries due to their distinct advantages in weight reduction and energy conservation [1]. Compared with the magnesium-rare earth alloy, wrought magnesium alloys with high aluminum content such as AZ80 and AZ91 have wider applications for their lower cost, excellent castability as well as moderate strength. Unfortunately, wrought magnesium alloys suffer from poor formability and strong mechanical anisotropy at room temperature because of the low-symmetry hexagonal close-packed crystal structure [2]. Moreover, as a precipitation-hardened alloy, the equilibrium β-$Mg_{17}Al_{12}$ phases obtained by aging treatment in AZ series alloy typically have coarse lamellar microstructure with wide inter-particle spacing and basal orientation with the matrix, which results in a weak aging hardening response and sacrifices the elongation evidently [3,4]. Contrasting with the static precipitation, dynamic precipitation is considered to be a dislocation-assisted process with whose morphology and volume fraction greatly depend on the deformation temperature, strain rate and strain [5,6]. Some recent investigations [7,8] showed that during hot processing, dynamic precipitations could refine the grain size by impeding the migration of DRXed grain boundaries, and thus leading to a multiple hardness increase of the alloy. In this regard, it is possible to improve the mechanical property of Mg-Al alloys by tailoring intermetallic phase (size, morphology and orientation) through suitable deformation processes.

Rolling is an effective processing technology to obtain high-performance magnesium sheets [9]; however, the intensive mechanical anisotropy greatly restricts their application. Texture and second phase are considered as the main contributors for the anisotropy in mechanical properties. Various methods have been introduced to reduce the mechanical anisotropy, such as changing the processing path [10] or introducing precipitates [11,12]. Previous researches about dynamic precipitation mainly focused on its formation condition and influence on dynamic recrystallization behavior [13–15]. Guo [13] reported that $Mg_{17}Al_{12}$ phases predominantly generated in the strain concentrate area and their volume fraction obviously increased with increasing the deformation strain. Xiao [14] believed that the temperature rather than strain rate played a dominant role in controlling the dynamic precipitation in Mg-Gd-Y-Zr alloy during hot compression. However, despite the above efforts, the information available in literature about the effect of second phase on anisotropy of magnesium alloys is limited, especially for the dynamic precipitations. Although several models concerning the influence of precipitation on anisotropy were proposed in aluminum alloy [16,17], it is insufficient to explain the results in other alloys since the precipitations they discussed usually possess

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http://dx.doi.org/10.1016/j.msea.2017.06.008
Received 20 December 2016; Received in revised form 1 June 2017; Accepted 2 June 2017
Available online 04 June 2017

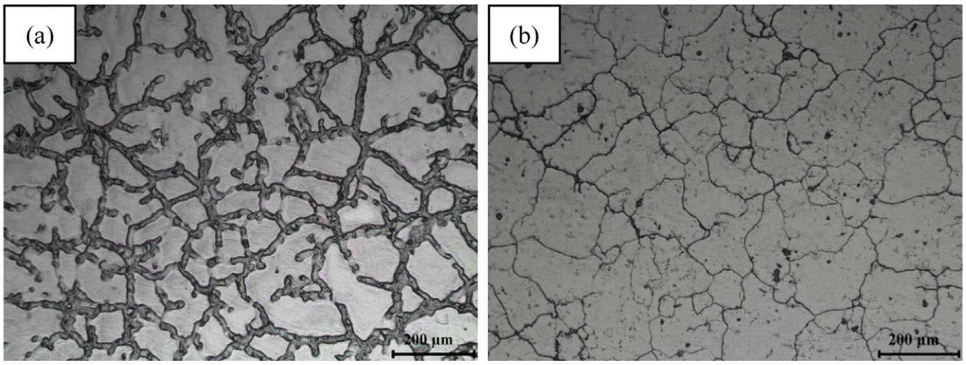

Fig. 1. Optical micrograph of AQ80 magnesium alloy: (a) as-cast and (b) solution-treated.

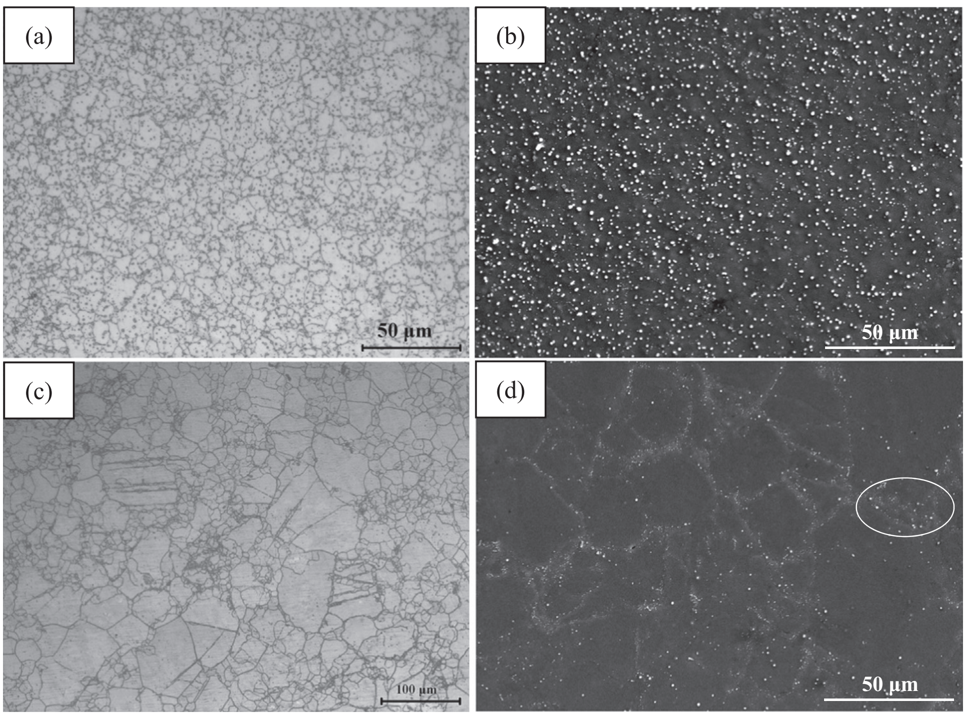

Fig. 2. Optical micrographs and SEM images of the rolled AQ80 sheets: (a) and (b) for 633 K (LT sheet); (c) and (d) for 673 K (HT sheet).

preferential alignment in specific shape.

In this work, the Mg-8.1Al-0.7Zn-0.15Ag (AQ80) alloy sheets were rolled at 633 K and 673 K, respectively. Dynamic recrystallization (DRX) and dynamic precipitation as well as their interactions in the hot rolled sheets were studied. Meanwhile, the influences of dynamic precipitation and texture on mechanical anisotropy were discussed so as to provide a useful guidance for the alloy design as well as microstructure design strategy for magnesium alloys.

2. Experimental procedures

An as-cast AQ80 magnesium alloy with the chemical composition of Mg-8.10Al-0.7Zn- 0.15Ag (wt%) was used in this experiment. Cuboid samples with dimensions of 53 mm × 50 mm × 24 mm were machined from the as-cast ingot and then homogenized at 693 K for 24 h, which led to a complete dissolution of network eutectic structure into the α-Mg matrix. The average grain size of the solution treated sample was about 140 μm (Fig. 1).

The rolling experiments were performed at 633 K and 673 K, respectively. For convenience, the sheet processed at the lower temperature was donated as LT sheet while that processed at the higher temperature was called as HT sheet. The solution treated samples were firstly kept at the corresponding deformation temperature for 30 min to ensure temperature equilibrium and the rollers were preheated to 523 K to prevent heat loss during deformation. The specimens were rolled from 24 mm to 6 mm in thickness. To reduce strain hardening, multiple passes were adopted with a reduction of 22–26% per pass and sheets were annealed for 10 min to stabilize the rolling temperature between each pass. Following completion of rolling, the rolled plates were immediately quenched into water to preserve the deformation microstructure.

Dog-bone tensile specimens with a gauge length of 25 mm and cross-sectional area of 6 mm × 3 mm were sectioned from the rolled sheets along the rolling direction (RD), 45° to rolling direction (RD-45°) and transverse direction (TD), respectively. The tensile tests were conducted on a MTS810 machine with a constant rate of 1 mm/min at ambient temperature. The mechanical properties of each condition were measured based on the average value of three specimens to confirm the repeatability.

The rolling microstructures were examined using Leica optical microscopy (OM) and Sirion200 field-emission scanning electron microscope (SEM). Constituent phases were identified by D/Max2500 X-ray diffraction (XRD) with CuK_{α} radiation while their characteristic observations were performed on JEM 2100F high resolution electron microscope (HRTEM) operated at 300 kV. The crystal orientation was analyzed by electron backscatter diffraction (EBSD) system with a step size of 0.6 μm. Samples for EBSD and TEM observations were prepared using conventional mechanical grinding followed by twin-jet electro